ETO

UNCLASSIFIED

RESTRICTED

OFFICE OF THE CHIEF SURGEON
U.S. Army. EUROPEAN THEATER OF OPERATIONS
A.P.O. 871

OPHTHALMIC ASPECTS OF CHEMICAL WARFARE

George I. Uhde, Major, M.C.
Gas Casualty Division, Office of the Chief Surgeon

With approval of Professional Services and Gas Casualty Divisions
Office of the Chief Surgeon

UNCLASSIFIED

RESTRICTED

INTRODUCTION

The information presented herein has been obtained by a review of the literature and by personal observation of casualties treated in the E.E.N.T. Clinic, Station Hospital, Edgewood Arsenal, Maryland, over a period of two years, and of experimental and accidental training casualties in E.T.O. during the past year.

A paper on the casualties treated at Edgewood Arsenal during the seventeen months preceding March 1, 1943, will appear in an early issue of the Archives of Ophthalmology. During this period 1,097 patients, of which 870 had eye lesions, were treated. The following gases were responsible for the eye casualties: mustard 790, tear gas 30, vomiting gas (DM) 24, lewisite 8, phosgene 7, white phosphorus 5, chlorpicrin 3, diphenylchlorarsine 1, chlorine 1 and sulfur trioxide-chlorsulfuric acid 1.

TEAR GAS

DEFINITION

A tear gas, or lacrimator, (1) is a chemical agent which causes a copious flow of tears and intense, though temporary, eye pain.

PHYSIOLOGICAL EFFECT

A droplet of liquid bromobenzylcyanide placed in the eye of a rabbit produces corneal edema and ulceration with fluorescein staining extending even to Descemet's membrane. Usually, however, the eye recovers in about 72 hours. Particles of solid chloroacetophenone entering the eye produce effects similar to those from droplets of bromobenzylcyanide. In September, 1943, while riding a bike across a firing range in E.T.O., a man was struck in both eyes with bromobenzylcyanide dispersed as a spray from a plane 50 to 75 feet overhead. Although he saw the spray leave the plane, the attack was so sudden that he was unable to shield himself. He felt drops enter both eyes and had instant severe pain with blepharospasm, lacrimation and photophobia - to such an extent that he fell off his bike. During the next 45 minutes the lid-spasm was so severe that it was practically impossible to irrigate his eyes. Three hours later, however, his subjective symptomatology subsided so that he was able to carry on with his usual duties.

His eyes were examined by slit-lamp an hour after contamination and the following findings were observed: moderate edema and injection of the conjunctivas, bedewing (edema) of the corneal epithelial cells with superficial punctate staining in the lower two-thirds of the corneas. Both eyes appeared normal two days later.

During the last war, Gremaux (2) examined tear gas cases and found a fine exfoliation of the corneal epithelium. It is interesting to note that many of the cases during the last war were hospitalized for as long as two weeks, and the soldiers complained of photophobia and lacrimation for three to four weeks. Unless there is secondary infection, facts now indicate that even in the most severe instances, these patients need not be hospitalized longer than 3 or 4 days.

PROTECTION

Gas masks afford complete protection. In an average field concentration, lacrimation begins to decline as soon as the mask is put on, but if droplets splash on the face and the mask is put on, the concentration within the facepiece builds up and incapacity results. Eye shields (3) eliminate the risk of droplets entering the eye but are of little value against vapor.

FIRST AID AND LATER TREATMENT

It is apparent from the preceding case history that lacrimators do not ordinarily have any serious effect upon an eye. Although irrigation is recommended, it appears to have little value: in the presence of the severe lid-spasm, the profuse tearing which results is probably as adequate as any irrigation from a canteen. Soldiers should be warned not to rub their eyes.

Instil one disc of fluorescein in the lower conjunctival cul-de-sac. Three minutes later, irrigate the conjunctival sac with normal saline, or with water from the canteen, to remove the excess fluorescein. Then examine the corneal surface carefully by means of focal illumination. If there is any green punctate or band staining of the cornea, instil one disc of homatropine hydrobromide every 15 minutes until dilatation of the pupil results. Do not use more than 4 discs of homatropine. (In the case of negroes, atropine must be used to obtain dilatation). Then evacuate the casualty. In the great majority of tear gas injuries, however, as already pointed out, the corneal damage will be temporary and so mild that it can only be detected by slit-lamp, so most of the casualties will not be evacuated.

VOMITING GAS

DEFINITION

A vomiting gas, or irritant smoke, sternutator, or sneezing gas, is a chemical agent which can be disseminated as extremely small solid or liquid particles in air, and when so disseminated cause lacrimation, sneezing, coughing, nausea and vomiting.

PHYSIOLOGICAL EFFECT

A white man aged 43, while working on a ventilating system at Edgewood, was suddenly exposed to a heavy concentration of DM particles. His immediate symptoms were severe sneezing, coughing, tearing and burning of both eyes. An upper respiratory burning sensation extended to the carina (bifurcation of the trachea). Nausea with vomiting, did not appear until about half-an-hour after exposure. With the vomiting, he developed a severe frontal headache which persisted for the next eight days. Epistaxis occurred. Both eyes appeared normal with 6X loupe examination except for slight conjunctival congestion and edema. Although the conjunctival changes cleared up in six days, the upper respiratory inflammation with severe hoarseness lingered for two weeks.

PROTECTION

It is important to remember that in slightly exposed soldiers symptoms may not occur until after the gas mask has been worn for some time; and in severely exposed individuals with a delayed onset of nausea and vomiting, e.g. one-half hour after exposure as in the preceding case history, the individual may be tempted to remove his mask prematurely.

FIRST AID AND LATER TREATMENT

There were unquestionably many more workers at Edgewood who had symptoms from the sternutator group but ordinarily all symptoms disappear after a few hours without treatment.

Later treatment is the same as that for tear gas.

CHOKING GAS

DEFINITION

A choking gas, or lung irritant, is a chemical agent which, when breathed, causes irritation and inflammation of the interior cavity of the bronchial tubes and of the lung.

PHYSIOLOGICAL EFFECT

On November 8, 1942, a female negro, aet. 19, at Edgewood was splashed in her left eye with phosgene, when a new worker became excited and dropped a tube of liquid phosgene on the table in front of the patient. Although the cornea did not stain with alkaline fluorescein, there was marked edema and hyperemia of the lids and conjunctiva with complaints of lacrimation, photophobia and blepharospasm. The eye recovered in 72 hours without any specific treatment.

In a sub-lethal concentration, phosgene causes lacrimation and coughing. Although the author has been unable to find a specific case report (4) and has never observed it in animals, it is stated frequently

in the literature that phosgene poisoning can cause retinal hemorrhage. It is postulated that the lung irritation results in a heavy loss of blood plasma into the alveoli causing hemoconcentration and anoxemia with damage to the endothelium of the blood vessels. Thrombi form in the cerebral and retinal vessels resulting in hemorrhages.

Chlorine, the first gas used in war, is a very powerful irritant and can cause slight corneal damage.

In a lesser concentration, chloropicrin is a strong lacrimator, though less effective than the true lacrimators, and the flow of tears is the first symptom noted. It was the only symptom in the patients treated in the E.E.N.T. clinic at Edgewood Arsenal. When splashed upon the cornea, liquid chloropicrin can cause ulceration and subsequent loss of vision.

FIRST AID AND LATER TREATMENT

Immediate irrigation with water from a canteen is as effective as any other treatment against liquid contamination.

Later treatment is the same as that for tear gas.

SCREENING SMOKES

DEFINITION

A screening smoke is a cloud of minute particles of solid or liquid, or both, suspended in a gaseous medium, usually the air.

PHYSIOLOGICAL EFFECT

Five patients with severe white phosphorus skin burns, treated in the hospital at Edgewood Arsenal, developed severe conjunctivitis; this was probably due to the two to five per cent copper sulphate solution used in treatment of the contiguous skin lesions. For this reason, it is preferable to use a one per cent copper solution in burns of the lids and adjacent skin. It is unlikely that very small particles of phosphorus struck the conjunctiva alone without some corneal damage. The burns were not due to smoke from the phosphorus since phosphorus smoke (phosphorus pentoxide) is harmless, although it sometimes causes severe coughing. Lyle and Gross (5) stated recently that in a search of the ophthalmic literature they were unable to find any record of phosphorus injuries of the eyes. They reported one case of a sclero-keratitis following a phosphorus injury 22 years before in a soldier who had scleritis with corneal scars deep in the substantia propria.

Phosphorus is being used extensively at the present moment not only as incendiaries but also as artillery fire to force the enemy out of fox holes. It may well happen that we shall see some severe eye burns from this agent.

On November 19, 1942, a white male, aet. 37, was treated for sulfur-trioxide chlorsulfonic acid burns of his left eye, left side of his face and neck and left forearm, when a "burster-well" in a leaking shell suddenly exploded. He ran immediately under a shower and his eye and skin were thoroughly washed. The eye burned and lacrimated but did not particularly disturb the patient until about 24 hours later at which time the lids were so edematous that he was unable to see. Other than swelling of the lids and conjunctiva, the eye appeared normal. The swelling subsided in 4 days and the skin burns healed in 7 days.

In February, 1943, in a Southern American Camp, a master sergeant, aged 24, splashed titanium tetrachloride in his left eye, while removing a cork from a bottle. The eye was irrigated immediately and for about five minutes with two per cent sodium bicarbonate. A medical officer gave him an ointment of metaphen 1-3000 with butyn 2 per cent with instructions to use it ad lib. Twenty-four hours later while en route to Edgewood Arsenal by train, the sergeant observed that his lids were severely swollen and that he had blurred vision with severe pain (relieved by the ointment), lacrimation, blepharospasm and photophobia. Examination three days after the eye was contaminated showed: severe inflammation of the lids and conjunctiva, numerous conjunctival and subconjunctival hemorrhages, central corneal ulceration 4 mm in diameter which stained bright green with fluorescein and which extended into the stroma, haziness (infiltrates and edema) of most of the remaining corneal tissue and reflex miosis. The aqueous was clear. The patient was placed in a dark room; the pupil was dilated with a mydriatic and albucid 10 per cent was instilled every 4 hours. The ulcer healed slowly leaving a faint nebular scarring in the visual axis.

PROTECTION

The ordinary eye-shields will give sufficient protection against all screening smokes except possibly white phosphorus. The protection afforded against phosphorus varies considerably: when a 11 mg piece of phosphorus, dried on blotting paper, was placed on an eye-shield and ignited with a hot wire, penetration occurred in 10 seconds. On the other hand, under similar conditions on one occasion, a 12 mg. fragment penetrated an eye-shield in 3.2 seconds. Even though the penetration time is rather rapid in some instances and, moreover, when disseminated from shells or bombs, the dispersal force may tend to decrease this penetration time

even further, the protection is probably sufficient to permit the lid-reflex time to protect the eye from a destructive burn.

FIRST AID AND LATER TREATMENT.

The contaminated eye should be irrigated with water to remove the particles of liquid as quickly as possible. In the case of white phosphorus, normal saline, or water from the canteen, should be used to wash out the eye.

The preceding case history is presented to stress the fact that although the great majority of burns from agents other than vesicants are not usually serious, occasionally, when an eye is contaminated at a point of dispersal, the destruction may be considerable. This is especially true if precautions are not taken to prevent secondary infection: viz., physiological rest (dark room, homatropine hydrobromide 2 per cent or atropine sulfate 1 per cent) and local antiseptics such as albucid 10 per cent or sulfathiazole ointment 5 per cent. Any soldier with his cornea denuded of epithelium should be evacuated. It is potentially dangerous to give such a patient a local analgesic, even though containing an antiseptic, for self-medication - the pain may be relieved but the pathology may progress.

INCENDIARY AGENT

DEFINITION

An incendiary is a substance which produces a heat burn when brought in contact with the body.

PYSIOLOGICAL EFFECT

In February, 1943, a T/4 aet. 27 was treated for thermite burns of both eyes, face, neck and both hands. He was drilling a hole into an experimental bomb which suddenly ignited. Fortunately, he was wearing spectacles. Examination showed: burns of the face, neck and hands; charred cilia; hyperemia and chemosis of both eyes; bright green fluorescein staining in the visual axis of the right cornea with either a pale green staining or haziness of the remaining corneal surface and superficial punctate staining of the left cornea. After treatment with a mydriatic and sterile liquid petrolatum in a dark room for 24 hours, the corneal surface no longer stained and presumably the epithelium recovered or regenerated.

PROTECTION

The gas mask furnishes the best protection. The anti-gas eyeshields give considerable protection, as shown in the discussion on white

phosphorus burns and by the fact that an eyeshield resists the flame of a bunsen burner for 3½ seconds.

FIRST AID AND LATER TREATMENT

The treatment (6) and prognosis is that of any heat burn of the same degree and extent. The eye should be gently irrigated with normal saline and a mild ointment or oil instilled. The lids should be closed with a pad of dampened gauze over them and a dry one held with adhesive, if possible - as the best dressing for the cornea is the lid. Cocaine or other local anesthetic should not be used, as anesthesia of the cornea might lead to damage.

BLOOD AND NERVE POISONS

DEFINITION

Blood and nerve, or systemic, poisons are casualty-producing agents which produce their main injuries effects only after absorption into the body and cause little or no local injury.

PHYSICLOGICAL EFFECT

Liquid hydrogen cyanide is rapidly absorbed through the conjunctiva: a drop placed in the eye of a rabbit causes convulsions in 45 seconds and death in 3 minutes. Some of the cyanogen halogens, e.g. cyanogen chloride (7), attacks the eyes causing lacrimation.

The specific action of arsine is that of hemolysis of the red corpuscles of the blood. Casualties from this agent will not usually be seen by the ophthalmic service.

Even in low concentrations, hydrogen sulfide (8) exerts a severe irritant action upon the cornea of an eye. The surface epithelium is eroded: probably by sodium sulfide which is formed from hydrogen sulfide.

INCIDENTAL AGENTS

DEFINITION

Incidental gases are those gases such as carbon monoxide, nitrous fumes, and ammonia which may act indirectly in confined or poorly ventilated spaces or in the bombing of industrial installations.

PHYSIOLOGICAL EFFECT

In carbon monoxide poisoning, the symptoms progress from headache, throbbing of the temples, vertigo, yawning, dyspnoea, dullness, and lack of visual acuity to the development of bright pink patches on the skin, marked weakness, coma with subnormal temperature, low tension pulse and death.

Nitric fumes cause conjunctivitis, rhinitis and pharyngitis followed by a latent period of 4 to 8 hours with no other symptoms until the casualty becomes suddenly, acutely ill with death in 24 to 48 hours from pulmonary edema. If the gaseous concentration is high, there may be a yellowish discoloration of the mucous membranes.

Ammonia vapor acts violently upon the eyes causing temporary blindness.

FIRST AID AND LATER TREATMENT

There are no specific first aid measures. The later treatment is the same as that for tear gas.

BLISTERING GAS

DEFINITION

A blistering gas, or vesicant, is a chemical agent which is readily absorbed by both the exterior and interior parts of the human body, followed by the production of local inflammation, burns and the destruction of tissue.

MUSTARD

INCIDENCE

The importance of mustard as a casualty-producing agent is shown by the fact that mustard (9) accounted for 70 per cent of all British gas casualties in World War I. The total number of British eye casualties is not known but Thuillier (10) (1919) gave the total number of British mustard gas casualties as not fewer than 150,000 and in the British Official History of the War: Medical Services (11) (1923) it is stated that the great majority of mustard casualties had eye burns.

Of these large number of British casualties (over 150,000) only ten (12) were thought to have corneal ulcers in which the vision became permanently impaired by residual opacities. There were four cases of panophthalmitis requiring removal of the eye.

In the American Expeditionary Forces (13) there were 27,711 casualties from mustard gas with only 599 deaths. Of this large number

of casualties, there were only 11 cases of blindness: two cases of loss of right eye, five with loss of sight of right eye, two with loss of sight of left eye, one with loss of sight of both eyes, one with loss of eye, side unknown. There were 33 cases of blindness due to all gases combined, the kind of gas in 22 cases (soldiers were frequently exposed to more than one gas) was not determined and may have been mustard. (It is interesting to note that there were 779 cases of blindness due to weapons other than gas).

Gilchrist in an analysis of 6980 mustard cases under his care during the last war showed that the parts of the body affected most often were:

(1) The eyes, 6080 cases or 86.1 per cent and

(2) the respiratory tract, 5260 cases or 75.3 per cent.

Of the 1097 patients treated at Edgewood Arsthal in the E.E.N.T. clinic during the 17 months preceding March 1,1943, 1016 (92.6 per cent) had burns caused by vesicant vapor, whereas the remaining 81 cases (7.4 per cent) were due to all other gases combined, also indicating to some extent how much more frequently vesicant vapor produces eye, and upper respiratory, casualties. Unfortunately, variation in production schedule and the shift of workers make it impossible to estimate with any accuracy the casualty rate in the various plants.

Striking, and surprising, was the finding that of the 1016 injuries due to vesicant, only 8 (0.7 per cent) of all patients) were caused by lewisite vapor and the remaining 1008 (91.9 per cent) of all patients) by mustard vapor alone. There are several factors responsible: (1) the lewisite plant is somewhat smaller; (2) higher vapor pressure of lewisite with immediate sensory irritation; and (3) the most important of all, mustard vapor is toxic in concentrations that cannot be detected by the sense of smell, and even when detected, the sense of smell soon becomes dulled and it is erroneously concluded that the mustard gas has disappeared. In other words, the soldier or worker exposed to lewisite vapor is warned instantly of his danger and either masks or leaves the contaminated area whereas on exposure to mustard vapor there is frequently no such warning. Therein lies, physiologically, the great value of mustard as a war gas and it is believed that the vast majority of eye casualties will be caused by mustard vapor.

Since the last war the preceding statistics of both the British and Americans have proved to be misleading for the following reasons: in 1929, Foster Moore and Heckford (14) described two cases of so-called delayed mustard gas keratitis. The marked features of these cases were:

(1) long interval (roughly ten years) between exposure to mustard and onset of corneal ulceration,

(2) extreme indolence of the corneal ulcers,

(3) lesions situated in the interpalpebral space,

(4) deep penetration of the ulcers even to Descemet's membrane,

(5) mild symptoms,

(6) slow healing, and

(7) the swollen, pearly-white, or marble-like appearance of the conjunctiva within the palpebral aperture.

T. J. Phillips (15) collected 70 of these cases of delayed mustard gas keratitis. All of these patients had been exposed to large doses of the gas and were apparently cured and symptom-free for a period of six to twenty years.

Dr. Ida Mann and others also reported similar cases of delayed keratitis. Since these cases were reported from only a very few of the large teaching ophthalmic centers, it is likely that there are many more cases of mustard gas keratitis being treated, the etiology of which is not being recognised by ophthalmologists in general.

DESTRUCTIVE DOSE

The destructive dose of mustard for the human eye is not known. The destructive dose for a rabbit's eye varies considerably: 0.0004 cc. of liquid mustard (4, 16) has caused destruction but it usually takes about 0.0008 cc.

Whether the human eyes with delayed keratitis were originally splashed with liquid mustard or exposed to mustard vapor is not known. It is probably relatively unimportant since it has been shown that concentration x time is fairly constant. In other words, a factory worker or a soldier exposed to a low concentration of mustard vapor (so low the individual does not mask) over a long period of time can develop as severe a burn as if his eye was actually splashed with liquid mustard.

After testing the eyes of 14 human volunteers whose cutaneous resistance was high, Reed (17) found that the eyes are the most sensitive structures to exposure to mustard gas and that concentrations of 1 part in 10,000,000 will produce visible reactions in less than one hour. That the eye is not always the most sensitive structure is shown by the fact that at Edgewood Arsenal there were 462 patients with lesions of both eyes and upper respiratory tract, 328 with eye lesions only and 218 with lesions of only the respiratory tract.

ONSET OF SYMPTOMS

There is a prolonged interval between exposure to mustard and the onset of symptoms.

Of 1008 patients treated at Edgewood Arsenal, only 80 knew when they had been exposed. These 80 knew because of a sudden accident, such as a break in the shell-filling line releasing large volumes of mustard vapor which was detected by the sense of smell. Of these 80 patients, the shortest interval between exposure and onset of symptoms was 2 hours, the longest, 24 hours, with an average of about 8 hours.

CLASSIFICATION OF EYE BURNS TO BE USED BY REAR ECHELONS (OPHTHALMOLOGISTS)

The British suggest the following criteria for the classification of mustard eye burns with the hope that diagnosis may be made easier and treatment simplified.

Group I: Of a very mild nature: The conjunctiva is congested and the lids may be red, but the cornea is clear. Edema of the lids and discharge may sometimes be observed. Although these appearances are due to the noxious action of the chemical substances, no permanent destructive change results.

Full duty should continue unless there are associated skin burns closing the eyes with edema.

Group II: Of a mild nature: Conjunctival congestion occurs together with thrombosis and hemorrhages. There is superficial corneal haze resulting from death of epithelial cells, and epithelial edema, processes which may effect individual cells here and there or which may be more generalised. In the field during the last war edema of the lids and discharge were common. Photophobia and blepharospasm are usual.

Only temporary incapacity is caused; there is discomfort for some 7-14 days during which light work can be done and after which there is no further trouble. (An ultimate prognosis cannot be made definitely in the more severe cases until the lapse of two weeks when it may be found that 50% may belong to Group III, fine deep changes in the cornea having developed).

Group III: Of a severe nature: Deep corneal haze is present in addition to the appearances described above. This group must be subdivided since it is not yet certain at which period vascularization of the cornea may develop, a factor on which the occurrence of relapses could seem to depend. (It has since been found that corneal vascularization starts about 40 days after contamination).

A. Temporarily severe: without new vascularization. Edema affects a varying depth of the substantia propria giving rise to evident haziness or to optical defects detectable by means of the slit-lamp. Death of corneal corpuscles take place followed by a cellular infiltration into the substance of the cornea. These cases need not be admitted to the hospital but should be kept under observation up to two months.

B. Relapsing: with new vascularization. In certain cases a growth of new vessels may take place from the limbus into the cornea. It is unknown at what period this occurs in man (now known to occur on about the 40th day after contamination), whether the vascularization may be transient, and how far its presence is associated with relapses (as in animals). Late optical or fibrous changes occur in the substance of the cornea.

Cases of this type should be admitted to hospital and will require convalescent treatment for a considerable time (several months). They may be liable to relapse.

A differentiation between A and B may be made before the lapse of six weeks; future knowledge may lessen this interval.

Group IV: Of a very severe nature: (in which delayed keratitis may occur after a lapse of years). A severe keratitis and perhaps iritis is followed by chronic keratitis, and later, by the deposition of degenerative material (cholesterin and fat) in the corneal substance.

These cases will be incapacitated and may be in a hospital for a period of six to nine months. They will be ineffective throughout the emergency and may be a future liability as a result of delayed keratitis. Such cases occurred after the last war. There are no accurate data available about what time may elapse before they can be differentiated.

Groups I and II should be termed Chemical Ophthalmia (Mustard Gas) and Groups III and IV Keratitis (Mustard Gas).

CLASSIFICATION OF EYE BURNS TO BE USED BY THE FORWARD ECHELONS (BATTALION, REGIMENTAL AND MEDICAL BATTALION SURGEONS).

Although the preceding classification is by far the best to date and should be used by Medical Officers with the proper clinical facilities (slit-lamp or loupe and condensing lens), it is felt by the Medical Field Service School, E.T.O. that the following would be of more practical value to Medical Officers in the forward echelons. There the problem is entirely different: it is not so much a question of prognosis but simply as to

whether a soldier is a casualty and should be evacuated for ophthalmic examination and treatment.

MILD CASES:-

a. Symptoms: Gritty, foreign-body sensation; may have very slight lacrimation, but no true photophobia.

b. Lids: May be slightly swollen, usually not.

c. Conjunctival discharge: May have slight lacrimation.

d. Conjunctiva: Congestion of only the conjunctiva normally exposed between the lids.

e. Cornea: Clear, does not stain with fluorescein.

f. Recovery: Spontaneous within five to seven days.

g. Treatment: None required, do not use a mydriatic.

h. Duty: Full duty, do not evacuate.

MODERATE CASES:-

a. Symptoms: Gritty foreign-body sensation and may have slight lacrimation, photophobia and blepharospasm.

b. Lids: Slight to moderate swelling, able to open eyes.

c. Conjunctival discharge: Slight to moderate lacrimation; may have slight muco-purulent discharge.

d. Conjunctiva: Congestion of the whole conjunctiva, even that protected by the lids.

e. Cornea: Clear, but may have punctate staining with fluorescein.

f. Recovery: Usually spontaneous within seven to fourteen days.

g. Treatment: If cornea stains with fluorescein, dilate pupil with homatropine; (in negroes use atropine).

h. Duty: Full duty if tactical situation is bad, evacuate later; if tactical situation is good, evacuate after mydriasis has been obtained.

SEVERE CASES:-

a. Symptoms: Severe gritty foreign-body sensation, ocular pain, lacrimation, photophobia, blepharospasm, blurred vision and headache.

b. Lids: Severe swelling, unable to open eyes voluntarily. Lids can only be separated a few mm.

c. Conjunctival discharge: Severe lacrimation with slight to very severe muco-purulent discharge.

d. Conjunctiva: Severe congestion, thromboses, hemorrhages, vessel variation in calibre and necrotic patches (stain yellow with fluorescein).

e. Cornea: Gray, hazy, irregular, roughened ("orange peel"), band staining with fluorescein. Hypoesthesia.

f. Recovery: Delayed at least many weeks; may be subject to relapses with corneal vascularization; requires ophthalmic observation for months and perhaps years.

g. Treatment: Atropine sulfate 1%, albucid 10% or sulfathiazole ointment 5%. Evacuate.

Some justification for the preceding classification is also shown by the fact that during the last war Whiting (18), who was in charge of the Ophthalmic Ward of the 83rd General Hospital, Boulogne, where over a third of all gas cases were treated, divided his patients into three classes: (1) slight cases with little or no corneal involvement - about 75%, (2) moderately affected eyes with slightly roughened cornea but not staining with fluorescein - about 15 per cent. and (3) severe cases with the cornea definitely staining and corresponding conjunctival involvement - about 10 per cent. Foster (19) found that the first class were fit for duty in one to four weeks, the second class in four to six weeks, while the third class, which was evacuated to England, required variable long periods for healing.

Although the duration of symptoms in the first two classes of Whiting's classification is prolonged compared with that in the first two groups of the Medical Field Service School Classification, the difference can probably be attributed to the fact that a soldier who knows that he is going to return to the front is frequently reluctant to part with his symptoms, whereas a factory-worker or a soldier acting as a volunteer experimental subject are usually only too glad to return to the factory (greater pay

incentive) or to the unit (friends, more comfortable surroundings).

DIFFERENTIAL-DIAGNOSIS OF CASUALTY AND NON-CASUALTY SOLDIERS

The following findings are those observed on six eyes splashed with liquid mustard, and insufficiently irrigated with normal saline, and six eyes exposed to mustard vapor during a recent training accident. The splashed eyes were casualties; the vapor-exposed eyes were non-casualties.

None of the casualties had any pain whatsoever when their eyes were splashed, confirming the experience of the last war. The mustard droplets felt like "watery" painless fluid. All the patients with splashed eyes complained of a severe gritty foreign-body sensation and of severe lacrimation, photophobia, blepharospasm and blurred vision three to twenty-four hours after exposure. Two of these patients complained of headache; there were no signs of iritis.

One of the patients with vapor-burnt eyes complained of a gritty foreign-body sensation and two complained of gritty foreign-body sensation and lacrimation about seven hours after exposure. One patient complained of mild photophobia. Three patients, although asymptomatic, had signs of a vapor burn.

The lids of the eyes contaminated with liquid mustard were so severely swollen (even as early as four hours after exposure) that the casualties were unable to open their eyes for days. Each had severe blepharospasm. Whereas, the lids of the eyes exposed to vapor only were never more than moderately swollen and without blepharospasm. It is believed, therefore, that severe swelling of the lids (except for that due solely to external lid burns) should be considered a sufficient criterion for evacuation.

Muco-purulent conjunctivitis due to secondary infection developed in four of six eyes splashed with mustard, being very severe in one instance. This is in marked contrast to findings in vapor-exposed but non-casualty cases.

The conjunctival changes observed in the splashed eyes were: severe congestion, thromboses of vessels, hemorrhages, necrotic patches with budding new vessels and marbling. Similar, but much lesser, changes were found in the limbus.

Four of six vaper-exposed eyes showed conjunctival congestion. The other two eyes had epithelial flecks. It is felt, therefore, that epithelial flecks have about the same diagnostic and prognostic significance as conjunctival congestion. Except for congestion and epithelial

flecks, the vapor-burnt eyes appeared normal. (Corneal epithelial flecks are seen by slit-lamp retro-illumination and are probably edema of individual epithelial cells. It is believed by some observers that these flecks are pathognomonic of mustard vapor exposure.)

Four of six splashed eyes showed band-staining, punctate staining, bedewing and epithelial flecks of the corneas. The other two eyes would probably have shown the same findings but the patients were too ill for slit-lamp examination. Five of these eyes had hazy, gray (opaque), irregular, faceted corneal surfaces ("orange-peel" or peau d'orange).

Five of six vapor-exposed eyes showed epithelial flecks (one patient was too ill with skin burns for slit-lamp examination). There was punctate staining of the epithelial cells in two cases and epithelial bedewing in another.

Five of six splashed eyes had edema of the anterior part of the substantia propria (two patients were too ill for slit-lamp examination, but one eye was examined histologically). Other stromal changes in this group were: complete edema, cellular infiltration, stratification and fibrous scarring. One of these cases had definite corneal vascularization on the 40th day.

Only one eye showed edema of the endothelium; the endothelial cells stained with fluorescein; the aqueous appeared normal.

DELAYED EFFECTS (SEE INCIDENCE)

From her work on rabbits Dr. Ida Mann (20, 21) believes that the picture of an eye which deteriorates into delayed keratitis is as follows: "At its edge (corneal scar) and in its base are cholesterin crystals. It is vascularized by peculiarly contorted and variscose vessels which enter through the normal limbus above and below the worse scars. There may be narrow constrictions, blood islands, intracorneal hemorrhages and thromboses. The scar shows, in addition to the cholesterin, white flocculent masses of fatty degeneration, patches of fibrillar silky texture and black and gray lines of a peculiar distribution." There may be a quiescent asymptomatic interval of six to sixteen years and then the cornea will suddenly ulcerate.

Bickerton (22) in 1943 described some cases of recurrent chronic conjunctivitis which he attributed to mustard gas lesions of the last war. Also, he described a case in which there was marked retinal degeneration and pigmentation with a fairly normal cornea and conjunctiva. It is unlikely that these lesions were due to mustard vapor; other observers have been unable to find any definite fundal changes.

Zettl (23) in 1940 described a case of recurrent chronic conjunctivitis occurring in a combatant injured in the last war and who had originally severe corneal ulceration.

Beauvieux, quoted by Hughes (24) examined the fundi in 120 cases of generalized mustard gas lesions and noted venous dilatation in 34 per cent and hyperemia of the optic disc in 23 per cent. These changes have not been seen by other observers.

Warthin et al described a Xanthoma-like pigmentation which develops near the outer and inner sclero-corneal junction.

It was observed in some of the negroes treated at Edgewood Arsenal that brown pigmentation of the conjunctiva extended into the superficial cornea, probably as the result of corneal damage from mustard vapor. It is a common observation in studying mustard-burnt rabbits' eyes that the denuded cornea heals by the healthy pigmented conjunctiva at the limbus migrating over the cornea carrying pigment with it. In rabbits the pigment later disappears.

FUNCTIONAL SEQUELAE

In the last war there was a high incidence of functional sequelae including photophobia and blepharospasm. Prolonged use of eye shades or glasses tended to perpetrate functional photophobia, functional blepharospasm and even hysterical amblyopia.

During a recent training accident in which some officers' eyes were splashed with mustard, the men became so excited that a medical officer had great difficulty in irrigating their eyes. One officer was so agitated for weeks thereafter that it was necessary to keep him in a private room so as not to disturb the other patients.

When there is moderate swelling of the eyelids, the patient frequently believes that his condition is far worse than it actually is. He sits with his eyes closed and complains of inability to open them. After some persuasion and gentle elevation of the lids, he is surprised to find that not only can he open his eyes but that he can see as well as before the accident. This experience happened to a very intelligent officer in ETO.

PROTECTION

Gas masks give complete protection to the eyes and lungs.

Eyeshields protect the eyes against drops, but cannot be relied upon to give protection against vapor.

TREATMENT

I. IMMEDIATE FIELD TREATMENT

The following recommendations for the treatment of mustard injuries of the eye were made by the American National Research Council:

"A. Vapor Burns:

1. The use of the gas mask is the best protection against mustard vapor burns.

2. Immediate lavage is not indicated, and should not be attempted for the following reasons:

a) Only a small percentage of vapor burns produce any serious damage to the eyes.

b) Experimental evidence indicates that immediate lavage of the eyes is without therapeutic value in vapor burns.

c) Any attempt to irrigate the eyes of a gassed soldier in the presence of vapor necessitates the removal of the gas mask with the resultant likelihood of further ocular and pulmonary damage.

B. Direct Liquid or Droplet Burns:

1. Eyeshields should be worn as protection against droplet injury.

2. Copious lavage with any available non-irritating fluid, including urine, is recommended if such can be accomplished within the first three minutes after the splash injury. The following points must be emphasized:

a) Lavage, to be effective, must be copious. Small volumes of fluid tend to spread not to remove the damaging agent.

b) Late irrigation is useless in the protection of the eyes, but up to 15 minutes after injury may be efficacious in removal of liquid mustard from lids and surrounding skin.

c) The difference in efficacy between different irrigating fluids is small, the difference between immediate and delayed irrigation is large, therefore that fluid should be used which is most immediately available. Water is among the most satisfactory fluids (canteen).

C. Specific Therapy:

No recommendation can be made at present for any specific or decontaminant therapy in the eyes.

II. LATER TREATMENT

A. Routine Lavage:

Late lavage as a routine is prohibited, but occasional lavage is permissible when required to remove foreign material, discharge and mucus. Experimental evidence indicates that routine lavage after injury is not only without any therapeutic value, but interferes with healing if repeated frequently.

B. Use of Atropine Sulfate:

1. Instill 1% solution of atropine sulfate in eyes at Gas Cleansing or First Aid Station in all cases of either vapor or direct liquid injuries of the eyes with mustard. (The author does not agree with this: if this is done, we may have a large number of atropine mydriatic casualties. See Gas Casualty Chest, use of supplies).

2. Further use of atropine, (or other cycloplegics) at the Base Hospital should be done only under medical direction - if, for example, there should develop a late iritis, corneal ulceration, or recurrent corneal erosion.

C. Local Anesthetics:

1. Local anesthetics may be used in both vapor and splash injuries of the eyes with mustard for the purpose of controlling pain.

2. The anesthetics recommended in the order of preference are:

(a) 0.5% pontocaine

(b) 1% butyn"

"3. Such local anesthetics should be used as little as possible and, at most, no more frequently than 4 times a day, and no longer than necessary. Frequent use of local anesthetics, especially cocaine, tends to loosen the corneal epithelium and delay the healing of eroded areas.

D. Shielding the Eyes:

1. Eyes injured either by vapor or direct liquid should not be bandaged or covered in any manner at the First Aid Post or Gas Cleansing Station. On the contrary, should there be sufficient edema of the lids present to prevent the gassed man from opening his own eyes, the attendant should gently open the lids for a moment to assure the patient he is not blind.

2. Bandaging at a later date should be done only for specific medical cause, such as corneal ulcers, corneal erosion, etc. as when the splinting action of the lids is required. If bandaged, the eyes should be dressed and cleansed once a day.

3. Dark glasses should not be used unless photophobia due to corneal involvement or iritis be present."

USE OF OINTMENTS CONTAINING SULFA-DRUGS

An ointment such as sulfathiazole 5 per cent or a solution such as albucid 3 to 10 per cent are recommended for use if there are any signs of secondary infection. Albucid is sodium sulphacetamide (sodium-p-amino-benzene-sulfonyl-acetylimide or sodium sulamyd). Best results are obtained with a 10 per cent solution instilled every 4 hours.

USE OF HYPERTONIC SOLUTIONS

Bonnefon advocated the use of hypertonic solutions on the grounds that a freer flow of lymph is produced in the conjunctiva. Such treatment is not recommended.

TREATMENT OF DELAYED MUSTARD GAS KERATITIS

Phillips, who has treated many of these cases, stated that the patients who did best were those that had tarsorrhaphy up to the time of fitting of a contact glass. Those treated by mydriatics, combined with lubrication, pad and bandage (remember these are late cases) also gave good visual results. Those treated by lubrication alone did not do so well as they appeared to have deeper infiltration than those treated by mydriatics.

Cases showing the poorest response to treatment were those treated with strong antiseptics such as silver nitrate, oxycyanide lotion and cocaine ointment.

Fortunately, these patients tolerate a contact lens exceptionally well (hypoesthesia of the cornea), resulting in improved visual acuity and giving protection to the cornea against external trauma.

NITROGEN MUSTARD

HISTORY

New war gases (27, 28) known as nitrogen mustards may be encountered in the event of gas warfare. There are several nitrogen mustards.

PHYSIOLOGICAL EFFECT

The clinical course after exposure to nitrogen mustard is similar to that after exposure to mustard vapor, the difference (in a rabbit's eye) being as follows:

During the exposure lacrimation, congestion and edema appear more rapidly in the nitrogen mustard eye.

At 24 hours there is less conjunctival swelling and less corneal staining in the mustard eye but in both eyes there is severe swelling of the conjunctiva and lids, marked edema of the superficial cornea and staining over more than half the corneal area.

At 2 days there is an extension of the edema into the deeper layers of the cornea and an increase in severity of the conjunctivitis of both eyes, but to a lesser degree in the mustard eye.

At 3 days pigment on the corneal surface of both eyes denotes early epithelization.

At 8 days in the nitrogen mustard eye, there are conjunctival hemorrhages, tortuous and injected conjunctival vessels, necrotic corneal ulcers extending into the substantia propria, edema of all corneal layers, deep as well as superficial corneal vascularization and an indistinct iris. In the mustard eye, there is more swelling of the conjunctiva, more discharge but less edema of the cornea. Moreover, there is only superficial corneal vascularization.

At 10 days a large surface hemorrhage appears on the iris of the

nitrogen mustard eye. The iris does not respond at all, or only very sluggishly, to light stimulation. In the mustard eye, some of the iris vessels are dilated but there are no exudates, no hemorrhages and the iris responds well to light.

At 16 days in the nitrogen mustard eye, the patchy necrotic corneal ulcers are becoming confluent and the vascularization is increasing. The iris is being depigmented. There are petechial as well as large surface hemorrhages in the iris. There may be an iris bombé, whereas, in the mustard eye the lid lesions are more severe with puckering and ectropion, the conjunctiva is more swollen, the corneal vascularization is still superficial and the iris appears normal.

At 20 days in the nitrogen mustard eye, there is only slight puckering of the lid margins and very little conjunctival discharge. Vascularization and edema of the cornea are severe and the corneal ulcers stain. There are fresh iris hemorrhages and in the old hemorrhages scarring is beginning with retraction and notching of the pupil edge. While in the mustard eye, the lid lesions are more severe and the conjunctiva more swollen, there is only superficial corneal vascularization, although progressing, and a normal iris.

At 27 days, in the nitrogen mustard eye, the lids and conjunctiva appear almost normal but there are hemorrhages in the heavy vascularized cornea and retraction of the iris to such an extent that the iris is drawn behind the limbus, resulting in a U-shaped pupil. Although in the mustard eye the lid and conjunctival lesions are still severe and the corneal scar is large with edema, the superficial vascularization appears to be subsiding and the iris is normal.

On August 11th, 1943, the left eye of a volunteer soldier, aged 22, was exposed to a vapor concentration, estimated to be sub-casualty, of one of the lesser effective nitrogen mustards, in order to compare its casualty-producing potencies with that of mustard.

The soldier was awakened 11 hours after exposure with a "gritty" sensation, lacrimation, photophobia, blepharospasm and subjective blurred vision. There was no objective change in his visual acuity, however. Slit-lamp examination showed innumerable flecks of the corneal surface and punctate staining with fluorescein. He was unable to carry on with his usual duties.

Examination two days after exposure showed all his previous symptoms and, in addition, a severe dull aching pain in and behind the left eyeball. There were innumerable epithelial flecks, epithelial bedewing and spots of epithelial staining. He was still unable to work.

Examination three to twenty days, inclusive, after exposure: he had all the previous symptoms and signs but he was able to partly perform his usual duties since the blurred vision was intermittent. The most annoying symptom was a dull aching pain in and behind the left eyeball. Corneal sensation appeared diminished on several occasions. The intensity of the epithelial staining varied from day to day - on the twelfth day after exposure, there were as many areas of punctate staining as at any time.

There was a gradual improvement until the twenty-fifth day at which time the eye appeared normal.

PROTECTION

Gas masks give complete protection. Eyeshields give the same protection as against mustard.

TREATMENT

The following treatment is recommended by the American National Research Council:

"The recommendations given for the treatment of eye injuries with mustard are equally applicable to eye injuries with nitrogen mustard. There is no additional or specific therapy. In general the symptoms and inflammatory lesions, iritis, etc. are more severe and more intensive and early cycloplegic treatment should be instituted."

LEWISITE

HISTORY

Lewisite is an arsenical compound which was developed towards the end of World War I and never actually used in combat.

PHYSIOLOGICAL EFFECT

The site of contamination of a rabbits' cornea with a lewisite droplet becomes immediately opaque. The lewisite appears to soak into the cornea almost instantaneously. There is obvious severe pain: the animals frequently squeal. The lid-spasm is very severe for about 15 to 30 seconds.

The pupil may constrict in about 2 minutes. The corneal epithelium, which is so hazy that it is difficult to make out the iris, begins to

loosen in about an hour and a half. The denuded surface stains with fluorescein. The conjunctiva is severely edematous with small hemorrhages. Edema extends into the substantia propria. It takes about 7 hours before the whole cornea becomes edematous. At 24 hours there is an iritis with strands of exudate in the anterior chamber. The limbus epithelium with its pigment begins to slide, or cover, over the denuded corneal surface. Vessels begin to invade the cornea from all parts of the limbus on the 6th to 8th day. The eye usually perforates in 2 to 5 weeks.

Although the pure substance is not lachrymatory, it is very irritant to the upper respiratory tract thus causing a reflex flow of tears.

It has been shown that lewisite vapor, surprisingly enough, does not cause corneal damage, at least in some animals, until large concentrations are reached.

PROTECTION

The protection is the same as for mustard.

TREATMENT

Although most liquid chemicals can be effectively and best removed by immediate irrigation with water, lewisite is an exception to this rule. Apparently, lewisite enters into combination with tissue cells so rapidly that it cannot be removed mechanically by immediate irrigation but must be neutralized. Fortunately, this can be done by an antidote developed secretly by the British and now used in the U.S. Forces under the name BAL (British Anti-Lewisite) and formerly called Eye Solution M-1.

The American National Research Council recommended, in part, the following treatment for all arsenical burns:

"Immediate Treatment:

1. BAL is an effective specific therapy for all lewisite and arsenical gas burns of the eye. It should be used as follows:

   a) As soon as possible after injury.

   b) A short period of disability and complete cure can be anticipated if BAL is used within two minutes after injury.

   c) The period of disability will be increased but complete cure may still result if BAL is used within the first five minutes.

d) The period of disability and the final damage increased markedly with further delay. If administered 30 minutes after injury, most injured eyes will eventually be sightless. No beneficial effect of any kind will be observed if treatment is not given within the first hour."

Eye Ointment, BAL, has displaced Eye Solution, BAL. It is much more difficult for the soldier to place the solution than the ointment into his eye. Eye Ointment, BAL, should be used as follows by the individual soldier (29): for any liquid contamination in the eye which is immediately painful, immediately squeeze a small amount of the ointment on to a finger-tip and rub firmly between the eyelids. Pull down the lower lid and insert the remaining ointment. Close the lids and rub firmly.

Late Treatment:

The late treatment is the same as that for mustard.

HOW IS THE SOLDIER GOING TO KNOW WHETHER TO IRRIGATE OR USE BAL OINTMENT?

The ideal solution would be to have a single ointment effective against both mustard and lewisite. Unfortunately, this is not possible at present.

The soldier should be instructed to irrigate his eye immediately after any painless, "watery-like" splash of his eye. Immediate irrigation is by far the most effective treatment against a mustard splash.

In any painful liquid contamination of his eye the soldier should be instructed to use BAL ointment.

What about the treatment of a 50/50 mixture of lewisite-mustard, which is also painful? It has been found experimentally that the best results in such contaminations are obtained by the instillation of BAL Ointment. The most logical procedure would seem to indicate immediate irrigation to remove the mustard and then to instil BAL to counteract the lewisite. However, numerous experiments have been carried out and refute this belief: namely, irrigation and instillation of BAL versus irrigation, instillation of BAL, and irrigation versus instillation of BAL. The best results are obtained by the simple instillation of BAL. There are two possible explanations of why this result is obtained: (1) BAL is very irritating and produces severe tearing which may act nearly, but not quite, as effectively as simple irrigation in the removal of the mustard, and (2) 0.0002 cc of lewisite destroys a rabbit's eye whereas it usually takes 3 or

4 times as much mustard to result in similar destruction, so that in a 50/50 mixture, the lewisite is doing more than its proportional share of damage. In other words, the amount of mustard present in such a mixture-droplet will usually not, by itself, produce any serious effect to an eye.

Moreover it has been shown that BAL ointment alone, if used within one minute, will save a majority of mustard-contaminated eyes, probably, again, as a result of the irrigating effect of the flow of tears caused by the irritant properties of BAL.

What about a liquid tear gas contamination of the eye which is painful? Dr. Ida Mann has shown that BAL Ointment does not increase the severity of such a lesion.

What about when the soldier is in doubt? He should instil BAL Ointment.

To reiterate, the soldier should be instructed to irrigate immediately in any painless "water-like" splash of his eye and to use Eye Ointment BAL in any painful splash.

USE OF SUPLIES IN GAS CASUALTY CHEST

Special drugs and equipment for treatment of gas casualties have been grouped for issue as the Set, Gas Casualty (Med. Dept. Item No.97757), (30-34 incl.). This set consists of two cases, Gas Casualty (Med. Dept. Item No.97758), containing impermeable aprons and gloves, and one Chest, Gas Casualty (Med. Dept. Item No.97759), containing drugs. The ophthalmic contents of the Gas Casualty Chest with directions for use are as follows:

Ophthalmic discs of fluorescein (1/250 grain, NSB-1), homatropine hydrobromide (1/250 grain, Item No. 91100) and atropine sulphate (1/200 grain NSB-1) are being placed in the Gas Casualty Chest. In the event of gas warfare, these discs are to be used as follows (35):

1. In case of doubtful corneal damage from any chemical whatsoever, instil one disc of fluorescein in the lower conjunctival cul-de-sac. Three minutes later, irrigate the conjunctival sac with normal saline, or water from the canteen to remove the excess fluorescein. Then examine the corneal surface carefully by means of focal illumination (condensing lens and light) and loupe (magnifying lens); of course, in first and second echelon care, only a flash light or North light may be available but the examination must be made in a good light (36). If there is any green punctate or band staining of the cornea, instil one disc of homatropine hydrobromide every 15 minutes until mydriasis (dilatation of the pupil). Do not use more than four discs of homatropine. Then evacuate the casualty. (In the case of negroes,

atropine must be used to obtain dilatation.)

2. Soldiers whose lids are so swollen that they are unable to open them and those lids can be separated involuntarily for only 2 or 3 mm. and, when so separated, complain of blurred vision, lacrimation, blepharospasm and photophobia, are already severe casualties. It is not necessary to instil fluorescein: the corneal surface usually appears roughened and hazy. Instil one disc of atropine sulfate every 15 minutes until dilatation of the pupil is observed. Do not use more than 4 discs. Evacuate at once.

3. Soldiers with hyperemia of only those conjunctival vessels normally exposed between the lids are not casualties and will recover spontaneously in a week to nine days. Do not instil homatropine or atropine, the mydriasis so caused will make the man less able to care for himself. This cannot be stressed too strongly because in the case of mustard the great majority of burns may be in this group.

The use of the following drugs has been discussed elsewhere in this report: Item No. IK 24810, Eye Solution, BAL (or M-1), ½ oz. and Item No. IK 24808, Eye Ointment BAL (or M-1), Tube (cf. Lewisite, treatment of); Item No. IK 76525, Sodium Sulamyd (Albucid Item No. IK 01085; cf. Mustard, treatment of; Item No. 91090, Eye and Nose Drops, 1 oz., contains pontocaine (cf. Mustard, treatment of, EE C, 2).

EVACUATION OF EYE CASUALTIES

Eye casualties from war gases are to be evacuated (37, 38) through the usual channels, supported, when necessary, by the Medical Gas Treatment Battalion (39).

Since eye-shields cannot be depended upon to give protection against vapor, the gas mask must be worn by those attending contaminated cases. During the last war (40), in the forward aid stations, there were many instances of every member of the staff in attendence on contaminated cases being rendered eye casualties. And even during this war, after a large transportation accident, over a hundred vapor eye casualties resulted from being exposed to mustard contaminated patients.

REFERENCES

1. Pochapin, I.M.: Aspects of Chemical Warfare, Penna.Med.Jour.45: 795-800 (May) 1942.

2. Gremaux quoted in the Medical Department of the United States Army in The World War, Vol.XI, Surgery, Part 2, War Department 1924, p.716.

3. Training Memo.42, Section II, Defense Against Chemicals in Combat, HQ. ETOUSA, 23 Dec. 1943.

4. The Medical Department of the United States Army in the World War, Vol.XIV, Medical Aspects of Gas Warfare.

5. Lyle, T.K., and Cross, A.G.: Sclero-Keratitis Following Phosphorus Injury of the Eye, Brit. J. Oph.26: 301-306 (July) 1942.

6. Circular Letter No. 8 Treatment of Thermal Burns, p.2, OCS, ETOUSA, 14 January, 1943.

7. Williams, H.E.: The Chemistry of Cyanogen Compounds, J. & A. Churchill, London, 1915.

8. Henderson, Y., and Haggard, H.W.: Noxious Gases, p.140, Reinhold Publishing Co., New York, 1943.

9. General Article: Diagnosis and Treatment of Gas Casualties, Brit. Med. J., 723-724 (May 10) 1941.

10. Thuillier, H.F.: Gas in the Next War, London, Geoffrey Bles, 1939, p.118-119.

11. Official History Medical Services, Diseases of the War, Vol.2, p.443, 1923.

12. The Lancet 10: 1: 296-297, 1942.

13. Gilchrist, H.L.: A Comparative Study of World War Casualties from Gas and other Weapons, Washington, D.C., Government Printing Office, 1931.

14. Moore, R.F., Heckford, F.: Delayed Corneal Ulceration from Mustard Gas, Brit.M.J.I.: 497-498 (March 16) 1929.

15. Phillips, T.J.: Discussion on Gas Injuries of the Eye, Proc.Roy.Soc. Med.33: 229 (Nov. - Apr.) 1940.

16. Warthin, A.S., Weller, C.V., Herrmann, G.R.: The Ocular Lesions Produced by Di chlorethyl sulphide ("Mustard Gas"), The Jour.Lab & Clin. Med.4: 785-832 (Oct.), 1918.

17. Reed, G.I.: The Minimum Concentration of Dichlorethyl sulphide (Mustard Gas) Effective for the Eyes of Man, J. Pharm. & Exper. Therap.15: 77-80, 1920.

18. Whiting, M.H.: Discussion on Gas Injuries to the Eye, Proc.Roy.Sec. Med.33: 225 (Nov. - Apr.) 1939-1940.

19. Foster, John: Ophthalmic Injuries from Mustard Gas, Brit.Med.J.2: 1181-83 (Dec.16) 1939.

20. Mann, Ida: Study of the Clinical Pathology of Mustard Gas Injuries to the Eyes in Man and its Correlation with that seen in Rabbits, Proc.Roy. Sec.Med.35: 236-244 (Jan) 1942.

21. ----------: A study of Mustard-Gas Lesions of the Eyes of Rabbits and Men, American Journ. of Ophthalmology 26: 1253-1277 (Dec.) 1943.

22. Bickerton, R.E.: New Cases of War Blindness due to Mustard Gas, Brit. Med.J.: 769-770 (Oct.27) 1934.

23. Zettl, W. (Abstract): Arch.Oph.26: 705-706 (Oct.) 1941.

24. Hughes, W.F.: Mustard Gas Injuries to the Eyes, Archives of Ophthalmology 27: 582-601 (March) 1942.

25. Krumbhaar, E.B.: Role of the Blood and the Bone Marrow in Certain Forms of Gas Poisoning: I. Peripheral Blood Changes and their Significance, J.A.M.A.72: 39-41 (Jan.4) 1919.

26. Hektoen, L., and Corper, H.J.: Effect of Mustard Gas on Antibody Formations, J.Infect.Dis.28: 279-285, 1921.

27. Circular Letter No.56, Nitrogen Mustards, OCS, ETOUSA, 13 April, 1943.

28. War Department: Training Circular No.86: Washington, November 13,1942.

29. Training Memo. 42: HQ ETOUSA, 23 Dec 1943.

30. Circular Letter No.72: Treatment of Gas Casualties, OCS, ETOUSA, 4 May, 1943.

31. Circular Letter No.81: Treatment of Gas Casualties, OCS, ETOUSA, 14 May, 1943.

32. Circular Letter No.108, Changes in contents of Gas Casualty Set, Item 97757, and Gas Casualty Chest, Item 97759, 21 July, 1943.

33. Circular Letter No.165: Supplies for treating Gas Casualties, OCS, ETOUSA, 13 November, 1943.

34. Circular Letter No.61 (Supply No.6): Repacking of Chest, Gas Casualty, M.D.Item 97759, OCS, ETOUSA, 19 April, 1944.

35. Letter OCS, 28 April, 1944: Changes in the Gas Casualty Chest.

36. Notes by Col. Derrick Vail: Field Ophthalmic Surgery, 183-5, Medical Field Service School, America School Center, ETO.

37. Basic Field Manual Defense Against Chemical Attack, Sept.7, 1942, FM 21-40, p.80.

38. CSO 704: Reception and Handling of Vesicant Gas Casualties in Fixed Hospitals, 22 May, 1943.

39. Basic Field Manual, Defense Against Chemical Attack, Sept.7, 1942. War Dept., FM 21-40, p.80. Medical Gas Treatment Battalion.

40. Poole, L.T.: Chemical Warfare in Relation to Ophthalmology. Modern Trends in Ophthalmology, Butterworths Medical Publications, London, 1940.